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WHITE PAPER - 102

New Methods for Moving Toward Zero Emissions While Minimizing Cost

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INTRODUCTION

The primary challenge currently faced by the power generation industry is meeting the increasing consumer demand for electricity while reducing airborne toxic emissions in compliance with federal regulations. The most recent regulations issued by the U.S. Environmental Protection Agency are the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). Emission reduction techniques generally fall into one of two categories: eliminating the pollutants at the source with improved combustion that optimizes heat transfer while minimizing pollutant formation, or removing them from the flue gas downstream. The use of overfire air systems and low NO_X (nitrous oxide) burners has become popular in coal-fired boilers. Low NO_X combustors for gas turbines have also been successful recently. Flue gas clean up equipment includes SCR/SNCR (selective catalytic reduction and selective non-catalytic reduction) systems for NO_X removal, flue gas desulfurization systems to remove SO_X (sulfur oxides), electrostatic precipitators for particulates, activated carbon injection for mercury removal, and many other variations. All of these techniques require uniformity of flow or thermal distribution for optimal performance, which can be very difficult and expensive to achieve through trial and error methods. This white paper introduces some efficient and inexpensive methods for maximizing performance of pollution control techniques, potentially eliminating the need for additional capital expense.

THE REGULATORY LANDSCAPE

The U.S. EPA recently released two rulings related to emissions from power plants: CAIR and CAMR1 .
Clean Air Interstate Rule (CAIR) Fine particles and ozone are viewed as a serious health hazard in the United States, having been linked to respiratory trauma, while sulfur deposition acidifies surface waters, damages forest ecosystems and soils, and contributes to decreased visibility. In the U.S., power plants generate 69% of the sulfur dioxide (SO_2) emissions and 22% of the NO_X emissions, which contributes to particle pollution and ground level ozone.

The Clean Air Interstate Rule was designed to help cities, specifically those in the eastern United States, meet new, more stringent national ambient air quality standards for ozone and fine particles, while maintaining economic strength, low electricity prices, and fuel diversity. It focuses on reducing SO_2 and NO_X emissions. It turns out that power plant emissions often travel across state lines, especially in the eastern U.S. where the states are smaller and there are more coal fired plants, which tend to produce higher emission levels. This means that a regional strategy must be employed, rather than a state-by-state approach.

The CAIR approach has been to set an emission reduction requirement for each state, based on capping power plant emissions collectively at levels that the EPA believes are economically achievable. With this, an optional cap and trade program will be implemented. This program allows an individual power plant to decide whether to pay for control technology or to buy emissions credits. Thus, the plants that are simplest and least expensive to retrofit will be the first to do so.

The states affected most are Minnesota, Iowa, Missouri, Arkansas, Texas, and all other states to the east, excepting Rhode Island, Vermont, New Hampshire, and Maine. Minnesota, Texas, and Georgia which are controlled for annual SO_2 and NO_x only, and Delaware, New Jersey, Connecticut, Arkansas and Massachusetts which are controlled for seasonal NO_x only. The rest are controlled for both.

It is estimated that CAIR will cost about $3.6 billion per year. By 2015, however, the savings in health costs will be between $85 billion and $100 billion, with further savings in later years.

The caps come in two stages:

Annual SO_2: 3.6 million tons in 2010 and 2.5 million tons in 2015

Annual NO_x: 1.5 million tons in 2009 and 1.3 million tons in 2015

Seasonal NO_x for ozone season: 580,000 tons in 2009 and 480,000 tons in 2015

These emission caps are divided into specific levels for each affected state, with each state deciding on how to achieve the required reductions, including source control determination and whether or not to join the trading program.

Clean Air Mercury Rule (CAMR)

Mercury emissions have become a concern in recent years, particularly in relation to fish contamination in fresh water in the East. Between 1990 and 1999, mercury emissions in the United States decreased by nearly 50%. Nearly all of the reduction, however, came through medical and municipal waste incinerators. The emissions from coal fired power plants decreased by just 4.3%, mercury being an inherent element in coal. In order to address the situation, the EPA recently released the Clean Air Mercury Rule (CAMR), which establishes standards limiting mercury emissions from both new and existing coal-fired power plants. It also creates a market-based cap and trade program, and comes in two phases.

The additional SO_2 and NO_x control equipment that will be required by CAIR will also cause some reduction in mercury emissions. This is typically referred to as the "co-benefit" of SO_2 and NO_x reduction. The first phase cap is 38 tons and it will be accomplished via phase 1 CAIR co-benefit. The second phase, due in 2018, entails a 15-ton cap. New coal-fired power plants (for any construction starting after January 30, 2004) will have to meet new source performance standards while also being subject to these caps. Like CAIR, the caps are distributed among the States, with the same flexibility in implementation.

While the first phase-in for CAIR is in 2009, the utilities optimizing their plants now will have the greatest advantage in the future, with the ability to sell emissions credits. Additionally, many plants are and have been under pressure due to comply with previously existing limits and rules.

Capital expenses for emission control equipment are high and utilities are actively looking for ways to reduce additional costs. With the added capability to sell emissions credits, maximizing performance of existing equipment adds value even when a plant is performing within regulations.

CAPS	CAIR	CAMR
	by 2009: 580,000 tons seasonal NO_x (ozone season) 1.5 million tons annual NO_x	**by 2010: CO-BENEFIT FROM CAIR PHASE 1** 38 tons annual mercury emissions
	by 2010: 3.6 million tons annual SO_2	
	by 2015: 2.5 million tons annual SO_2 1.3 million tons annual NO_x 480,000 tons seasonal NO_x (ozone season)	**by 2018:** 15 tons annual mercury emissions

FLOW MODELING AS A PATH TO INEXPENSIVE POLLUTION CONTROL

Computational flow modeling has become the premier tool for guiding engineering solutions to emissions control problems while eliminating or minimizing capital expenses. The method involves the use of numerical methods to solve fluid flow problems, which can also involve heat and mass transfer, chemical reactions, and phase change. Commercial flow modeling tools have been around for 20 years, and are currently being used in the power generation industry, but recent advances in computer speed and cost have made the technology ubiquitous for equipment design and optimization as well as troubleshooting of existing equipment.

Some plants may choose to lower NO_X emissions by merely optimizing combustion in burners and furnaces. Others, who may be using gas turbines or may have more stringent requirements, will use this tool to guide low cost improvements to post-combustion control equipment.

Combustion Optimization

Through the use of overfire air systems, reburn technology, and low NO_X burners, NO_X can often be reduced by up to 30%. These technologies involve very low capital cost, but achieving the maximum performance without the use of threedimensional computer modeling would require an unacceptable amount of downtime during tuning and trial and error testing. Flow modeling allows the engineer to investigate the performance through virtual prototyping. The results of the model include both quantitative and qualitative data, showing detailed three-dimensional information at every point in the boiler along with flow structure. This information provides guidance to improve the design. The new design performance can then be proven before being implemented in the field.

Today, the major low NOx burner manufacturers use flow modeling not only to guide the design of their burners, but also to investigate the performance of their burners in particular furnace installations.

Post-Combustion Equipment

Some power generating companies will find that after retrofitting a plant with postcombustion clean-up equipment, performance is lower than expected. The equipment is generally designed with an assumption of evenly distributed temperature, humidity, species concentration, and velocity fields. Very often, the root cause of an underperformance problem is poor flow distribution. When this occurs, flow modeling is employed to understand the problem and the results are then used to redesign a duct or injection system. The redesign can involve reconfiguration of turning vanes, changes in duct angles or cross-sections, redistribution of injection points, or addition of perforated plates or grids. Again, the performance of the new design can then be proven before it is implemented.

Analysis Scenario A:

Problem:

New CO and NO_X control equipment underperforms due to flow non-uniformities

Solution:

- Discovered velocity at ammonia injection grid was non-uniform, resulting in insufficient mixing of ammonia by the time it reached the catalyst
- Visualized tendency for flow to concentrate at the bottom end of pollution control unit, and complex circulations near top of expansion zone

Results:

- 20% improvement in velocity distribution was achieved; more than 90% of the flow upstream of the SCR has velocity within 15%± of average velocity
- System installed in field and measurements confirmed improved performance and exceeded regulatory requirements

Analysis Scenario B:

Problem:

Need to improve flow distribution coming into ESP ducting and redesign system to minimize pressure drops, reduce erosion on turning vanes, and reduce number of vanes; analysis to be completed within restricted timescale - goal to implement changes during shutdown period

Solution:

- Found non-uniform flow distribution in each duct and outlet, causing pressure drop and resulting inefficiencies
- Redesigned vanes; modified corner locations to optimize flow velocities

Results:

- Five sections improved for overall reduction in pressure loss of 40% in main duct
- Stagnant regions of previous system completely eliminated
- Total number of vanes cut from 206 to 76
- Performance improvements immediately evident when plant brought online following shutdown

Analysis Scenario C:

Problem:

Necessary to optimize elements of NO_X reburn method, specifically co-firing elevations and operation at varying loads

Solution:

- Analysis performed in conjunction with field test program using a portion of parameter range, then broader parameter ranges studied by flow modeling alone due to speed and cost

Results:

- NO_X exhaust levels dropped by 20% by optimizing air to fuel ratio for primary burners and extension of reducing zone
- Further analysis revealed an additional 30% reduction in NO_X when reburning with pulverized coal

While costs in the above scenario are reduced compared to a trial and error approach during a shutdown, experienced utilities are demanding flow modeling upfront with the purchase of post-combustion emissions control equipment, avoiding the cost of a redesign altogether.

SUMMARY

Maintaining low-cost power production while minimizing emissions has become the primary technical challenge for the electric power industry. While CAIR and CAMR are the most recently released rules from the U.S. EPA, most utilities have been continually reducing emissions to stay within existing state and federal requirements. Capital expenses for emission reduction are avoided when possible by optimizing combustion processes, but given the value of trading credits, optimizing performance of post-combustion equipment is also necessary. Three-dimensional flow modeling is a valuable tool and service that is available to utilities and engineering organizations in the industry, allowing both minimization of capital expenses and performance optimization of new equipment.

[1] Web seminar presentation by Roman Kramarchuck, Office of Air and Radiation, USEPA, "Virtual Prototyping to Improve Power Plant Emissions," hosted by Fluent Inc., April 28, 2005.

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